AD-A038 805 ANALYTICAL SYSTEMS ENGINEERING CORP BURLINGTON MASS F/G 20/9
ELECTRONIC RADIATION IN THE VICINITY OF SYNCHRONOUS ORBIT SATEL--ETC(U)
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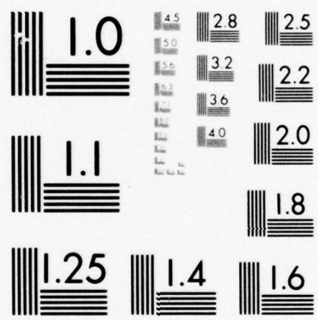

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AFGL-TR-77-0024

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ELECTRONIC RADIATION IN THE VICINITY OF SYNCHRONOUS ORBIT SATELLITES: Literature Search

George A. Bakalyar

New
Analytical Systems Engineering Corporation
5 Old Concord Road
Burlington, Massachusetts 01803

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Scientific Report No. 1

18 January 1977

Approved for public release; distribution unlimited

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE (18) (19)		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-77-0024	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) ELECTRONIC RADIATION IN THE VICINITY OF SYNCHRONOUS ORBIT SATELLITES: LITERATURE SEARCH		5. TYPE OF REPORT & PERIOD COVERED Scientific Report No. 1
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) ~~MR.~~ GEORGE A. BAKALYAR	(11) 18 Jan 77	8. CONTRACT OR GRANT NUMBER(s) (15) F19628-76-C-0203 New
9. PERFORMING ORGANIZATION NAME AND ADDRESS ANALYTICAL SYSTEMS ENGINEERING CORPORATION 5 OLD CONCORD ROAD BURLINGTON, MASSACHUSETTS 01803		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N/A
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscom AFB, Massachusetts 01731 Monitor/John F. Kellaher/SUYA		12. REPORT DATE January 18, 1977
		13. NUMBER OF PAGES 32
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 31p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

(14) Scientific-1

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

BREAKDOWN, DISCHARGE CURRENTS, UNSTABLE PLASMA, SATELLITE CHARGING, MAGNETOSPHERE SYNCHRONOUS ORBIT

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A categorized list of representative references are presented that apply to the task of estimating and predicting undesirable radiation incident to a satellite in synchronous orbit. The categories of references address basic elements of the task. That is, some references apply to estimating the particle and field environment about the satellite and other references are relevant to estimating the behavior of the medium, either as supporting of electrical discharge or the excitation of radiation → next page

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cont through instability and/or the presence of plasma boundaries. Both theoretical and experimental references are included in each category where possible.

The breakdown of Plasma, which is a "necessary" condition to the generation of discharge currents in plasma, is a much studied phenomenon both theoretically and experimentally. The references 6a of this report, together with the bibliographies associated with each reference, provide a representative information base to support either a critical review of important elements of breakdown and electrical discharge literature from about 1960 to the present time, or an ordered resume of breakdown characteristics as determined in that time period.

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ELECTROMAGNETIC RADIATION IN THE VICINITY
OF SYNCHRONOUS ORBIT SATELLITES:
LITERATURE SEARCH

1. INTRODUCTION

A satellite at synchronous altitude acquires a charge, sometimes of extreme magnitude, which can adversely affect on-board electronics by subjecting them to large electromagnetic stress. A possible source of such undesireable radiation, for example, can originate from the power coupled from breakdown currents flowing near the satellite. Another potential source of disruptive radiation occurs if the charged satellite excites an unstable plasma to radiate from the plasma interior or boundaries. Instability can possibly produce a turbulent wake with associated noisy radiation. Though all these mechanisms are possible sources of undesireable radiation, emphasis is initially placed on discharge phenomena.

It is important to develop realistic estimates of the levels of radiation associated with the satellite motion through the complex and variable magnetospheric plasma. Plasma behavior is modelled by equations that contain defining plasma parameters and a number of characteristic terms. The more complex the plasma model, the more difficult is the solution of the plasma equations. Realistic calculations should use the simplest plasma models that adequately predict discharge currents and/or waves excited in unstable plasma.

This report begins the task of generating realistic estimates of satellite radiation levels and is concerned mainly with acquiring and

categorizing a suitable information base. The report is intended to present a systematic approach and to exploit the present state of the art of plasma physics where possible and profitable. The accompanying literature search provides an overview of this many sided subject as it applies to the objectives of the investigation.

The mechanism responsible for disturbing radiations produced by a charged satellite's interaction with its plasma environment depends in one instance on the time dependent behavior of a plasma that changes due to external and/or self-consistent fields. In the other instance, radiation depends on the excitation of the complex plasma medium.

In the first case, it is required to know the initial conditions of the medium and to have models to describe behavior at later times. In the second case, it is required to know the dispersion characteristics of the medium and interaction criteria that determine the excitation of waves or oscillations in the body of the plasma or at boundaries.

In either case, the appropriate plasma model used to predict currents, or waves and oscillations can be generated by estimating certain plasma parameters (see Figure 2). These depend fundamentally on particle species, densities, energies, cross sections for various reactions and field strengths.

The block diagram of Figure 1 displays the components of the plasma medium (ambient and satellite generated) that contribute to the total environment.

The literature search is organized into categories as displayed in Figure 1. The elements of Figure 1 are further discussed on Page 5 .

It was judged useful to include an appendix to the report, in which the following items are given as additional information:

A. A list of defining plasma parameters in general use.

B. A block diagram displaying the relationship between plasma parameters that define a plasma model.

The literature search also includes a list of references related to the lightning discharge mechanism, because this familiar and much studied phenomenon has features that resemble those of the charged satellite:

- A charge separation mechanism powers discharges in each case.
- $\overline{E}$ fields must become intense enough to break down the medium (ionize it) so that discharge currents can flow.

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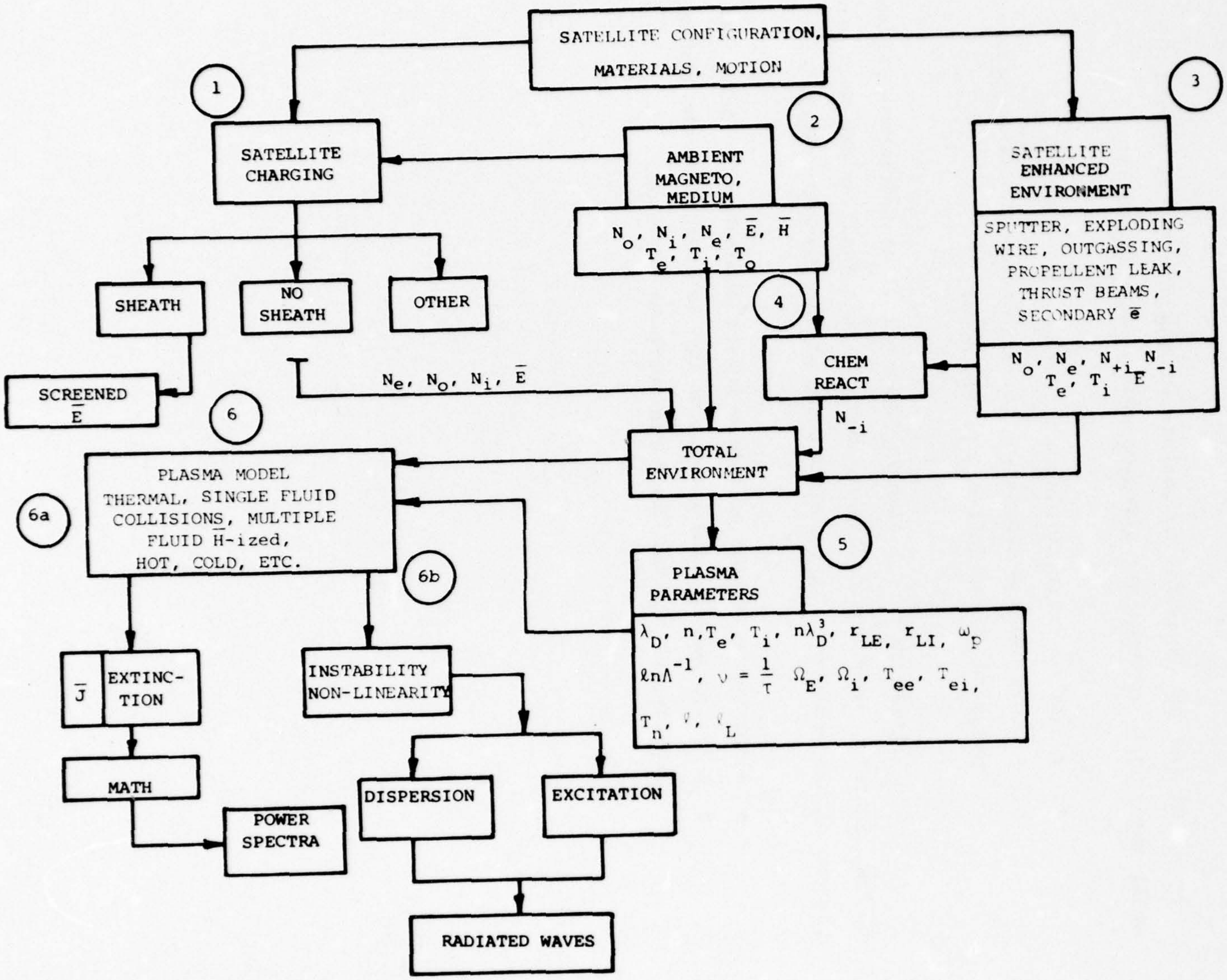

Figure I. Flow Chart Satellite Charging Literature Search

The categories 1 through 6 a, b displayed in Figure 1, identify independent areas of literature search that are "input" to the tasks of estimating radiation incident to a synchronous orbit satellite from external media. Before estimates of discharge current generated spectra or of waves and/or oscillations excited in unstable plasma can be attempted , a description of the plasma medium is necessary. Only then, can the synthesis of a suitable plasma model be initiated to generate the desired estimates and predictions in accordance with the state of the art plasma physics.

The categories 1, 2, 3, 4 determine the total plasma environment, and each category is a somewhat independent area of theoretical and experimental research. The symbols N_o, N_i, N_e $\bar{E}$, $\bar{H}$, T_e, T_i, T_n are descriptive of the basic constitution of the medium (particle densities, energies and the interacting field environment). The relative magnitude of ambient particle fluxes is also an important determinant in Category 2 and is not shown in Figure 1. The other symbols are defined as follows:

N_o = number density of neutrals
N_i = number density of ions
N_e = number density of electrons
$\left.\begin{array}{l}\bar{E} = \bar{E} \text{ fields} \\ \bar{H} = \bar{H} \text{ fields}\end{array}\right\}$ externally applied and self consistent fields
T_e = electron temperature
T_i = ion temperature
T_n = neutral temperature

In the neighborhood of a synchronous satellite, the above items can be complex functions of position within a Debye length of a satellite surface where discharges must originate. Part of the task of estimating discharge currents, for example, is to introduce reasonable simplifications and approximate plasma models in regions sensitive to breakdown and lying within this sheath.

The Category 5 representative references address the task of estimating plasma parameters that are suitable to define plasma models. The plasma parameters are defined in Appendix A.

Category 6 includes references relevant to the task of selecting an appropriate plasma model sufficient for the objectives of interest. The definition of plasma models is given in Appendix B.

The references 6A apply to the Task of estimating the $\bar{E}$ field strength producing breakdown of plasma, the conductivity of the plasma and other conditions critical to discharge currents produced in the broken down plasma, as powered by the satellite induced charge separations. The references are chosen to deal with elements of analysis essential to estimating currents realistically and in the present state of the art of plasma physics.

The references 6B apply to waves and oscillation produced in unstable plasma.

2. BIBLIOGRAPHY OF REPRESENTATIVE REFERENCES

Although discharge of a charged satellite can occur either through material breakdown within the satellite itself or by breakdown of the external medium, this literature search examines only the case of radiation produced in the external medium. Strong discharge currents require that the plasma be broken down (ionized by electron impact). Hence, the region of interest must contain sufficiently strong $\bar{E}$ fields. This limits the region of interest (in the case of discharge phenomena) to the plasma sheath enveloping satellite surfaces, because the fields are screened in regions beyond the sheath.

The plasma models must be sufficiently realistic to describe a plasma that is not quasi-neutral and also include the relevant inelastic, elastic and diffusion processes that determine the magnitude of breakdown $\bar{E}$ fields and the subsequent time dependent behavior of plasma. Other radiation mechanisms depending on plasma instability may not necessarily be confined to the plasma sheath or necessarily require that plasma be electrically broken down.

The initial conditions for the plasma in the sheath depend on the satellite charging process and possibly on its time dependent behavior in building up charge and $\bar{E}$ fields. The references 1.1-1.7 are concerned with this process. Reference 1.3 is particularly oriented toward formulating the basic physical and mathematical model of satellite charging.

The breakdown of plasma in the sheath can be investigated theoretically, leaving the initial conditions open, and using a suitable set of plasma equations (model). The magnitude of the *minimum* breakdown $\overline{E}$ field depends to a large degree on the amount of easily ionizable material present. Thus, the products of the interaction of ambient particles with the satellite surfaces that produce neutral particles (e.g., neutrals reflected, +ions neutralized, outgassing, sputtering) are possibly critical to breakdown characteristics. Also relevant to breakdown are the changes in the medium produced by products of thrusting systems. A neutral system may produce easily ionized or attaching molecules. An ionized thrust beam (satellite generated) can clamp the satellite potential to some lower value manifested in plasma external to the sheath. These considerations are the subjects of references 3.1-3.4.

Because unusual chemical reactions can occur in the presence of the discharges, the references 4.1 and 4.2 are included. Of most interest is the possibility of negative ion formation and the effect on breakdown of low ion mobility compared to the mobility of electrons.

The references of Category 5 consider criteria in standard use to develop plasma models.

The references 6A are chosen as representative of those that are concerned with both theoretically oriented and applications oriented aspects of plasma behavior. The list of DDC reports on Electrical Arc and Plasma contains a mix of theoretical and experimental investigations of breakdown

behavior of plasma. Similarly, a theoretical and experimental mix can be found on more general plasma subjects in references 6A6-6A12. The reference 6A16 is of practical interest, as it parameterizes the cross sections of inelastic reactions (exciting, ionizing) through a "Maxwellian Model". A similar approximate modelling of reactions in the collision integral may be sufficient for the breakdown investigations of interest.

The references 6B, dealing with instability are chosen to be representative. Reference 6B1, which has also been cited elsewhere, presents an extensive bibliography. Once the appropriate plasma model is determined (refer to Figure 2 in the Appendix) it is expected that a considerable narrowing of the field of relevant references can be readily effected.

The references 6B3 and 6B4 examine the dispersion expressions using linear theory. Other references seem to establish the ability of linear theory to predict stability, though non-linear theory (refer to 6A21) is needed to describe the unstable behavior. The references 6B5 and 6B6 investigate the two general categories of plasma instability independently.

The possibility of a radiating turbulent wake developing should the plasma be unstable has been mentioned briefly in reference 1.3. The conjecture was applied to a satellite moving through the ionosphere. Whether this possibility is also applicable to the magnetospheric medium is perhaps even more conjectural. However, the references 6B7 and 6B8 on turbulence have been included as possibly relevant references.

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FEB 71 71P BENENSON,D. M. ;CENKNER,A.

AD-A007 633 20/3 20/9
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MAR 73 14P SCHREIBER,P. W. ;HUNTER,A. M. ;TAYLOR,P. ;BENEDETTO,K. R. ;

AD- 713 131 20/9 20/3
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DESCRIPTIVE NOTE: FINAL REPT.,
AUG 70 278P HUNTER,A. M. , III

AD- 706 585 20/9 7/4
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PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON IONIZATION PHENOMENA IN GASES (14TH). HELD AT UPPSALA ON 17-21 AUGUST 1959. VOLUME I. (U)

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AD- 687 181 20/9
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BEAM PROBE MAPPING OF RAPIDLY FLUCTUATING PLASMA DENSITY IN AN ENERGETIC ARC. (U)

DESCRIPTIVE NOTE: REPT. NO. 4 (FINAL), 1 DEC 67-30

AD- 821 435 20/9
ARNOLD ENGINEERING DEVELOPMENT CENTER ARNOLD AIR FORCE STATION TENN

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AD- 750 477 20/9
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AD- 749 552 20/9
VANDERBILT UNIV NASHVILLE TENN DEPT OF PHYSICS

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DESCRIPTIVE NOTE: FINAL SCIENTIFIC REPT. 1 SEP 71-31

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RENSSELAER POLYTECHNIC INST TROY N Y PLASMA DYNAMICS LAB

CURRENT DENSITY AND SPACE POTENTIAL IN PLASMAS. (U)

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SELECTED PAPERS PRESENTED AT THE SECOND ARC SYMPOSIUM OF THE ANNUAL GASEOUS ELECTRONICS CONFERENCE (23RD) HELD AT HARTFORD, CONNECTICUT ON 20-21 OCTOBER 1970. (U)

DESCRIPTIVE NOTE: FINAL REPT.,

AD-A019 457 20/9 20/5 9/3
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AD- 731 803 20/9
SYSTEMS RESEARCH LABS INC DAYTON OHIO

ARC MOTION AND MODES IN A HOMOPOLAR DEVICE.

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AEROJET-GENERAL NUCLEONICS SAN RAMON CALIF

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AD- 754 228 12/1 20/4 20/13
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APPLIED MATHEMATICS

ON AN EQUATION RELATED TO NONLINEAR
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DESCRIPTIVE NOTE: TECHNICAL NOTE,
AUG 72 25P CAP,FERDINAND ;LASHINSKY,

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A TEST FOR THE VIABILITY OF FLUID CODES IN
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3. CONCLUSION AND RECOMMENDATIONS

An initial review of the literature in the categories chosen for literature search reveal that all categories are much involved with various aspects of plasma physics. A critical review of the literature in each category then appears to be a logical next step. However, because the objectives are relatively narrow,requiring the estimation of radiation incident to a synchronous satellite, it is expected that the depth to which each category need be investigated, can be correspondingly moderated.

Assuming that radiation produced by discharge currents in external media is the most likely source of undesireable external radiation, suggests that analysis begin with the electrical breakdown of diffuse plasma. A plasma model which includes a set of expression for charge continuity, current or momentum density and energy balance and is descriptive of a suitable multi-component plasma is first generated. The model is chosen to apply to a range of plasma parameters descriptive of the synchronous satellite's tenuous particle and field environment.

Electrical properties such as conductivity and self inductance of discharge streamers is then estimated. The synthesis of discharge current wave forms can be undertaken as determined by the time dependent processes of charge separation, plasma breakdown, discharge streamer growth , and discharge current flow with equalization of charge separation.

In focusing investigation in this manner, a range of estimated current wave forms and their spectra corresponding to a range of satellite plasmas can be generated. These can be compared with experimental measurements and with satellite data as a basis to refine or alter plasma models and calculations.

APPENDIX A

PLASMA PARAMETERS

β - ratio of plasma pressure to $\bar{H}$ pressure $= 8\pi n \frac{kT}{B_o^2}$

$\eta_\sigma (cm^{-3})$ - particle density (specie σ, $\sigma = e \rightarrow$ electron)

$T(o_k)$ - absolute temperature

$B(G)$ - $\bar{B}$ field in Gauss

$\lambda_D(m)$ - Debye length $= \sqrt{\frac{\varepsilon_o kT}{e^2(1 + Z^2)\, n_e}}$ (MKS units)

$\frac{4\pi n\lambda_D^3}{3}$ - number of particles in a Debye sphere

$\ell(cm)$ - characteristic scale of plasma region

$\lambda(cm)$ - mean free path $= C_{th}/\nu$

$\nu(s^{-1})$ - collision frequency of a particle

$u_\perp$ is velocity $\perp$ to $\bar{B}$

$r_{LE}(cm)$ - electron gyration radius - $m_E\, u_{\perp E}/eB$

$r_{LI}(cm)$ - ion gyration radius $= m_I\, u_{\perp I}/eB$

$\Omega_E(s^{-1}) = e\, B/m_e C = \frac{u_{\perp E}}{r_{LE}}$ = Larmor frequency of electrons

$\Omega_I(s^{-1}) = e\, B/m_I C$ = Larmor frequency of ions

λ_L = mean distance of closest approach $\rightarrow$ PE. = K.E

(i.e., $l_L = Ze^2/kT = 1.67 \times 10^{-3}\, Z\, T^{-1}$)

$\ell n(\Lambda^{-1}) = \ell n \frac{\lambda_D}{\ell_L}$, $\Lambda^{-1} = 4.9 \times 10^{14}\, T^{\frac{3}{2}}\, n^{-\frac{1}{2}}$

NOTE: Λ is an important parameter which indicates the degree to which collective effects exceed individual particle effects.

C_{th} = thermal velocity = $\sqrt{\frac{3kT}{m}}$ m = particle mass

$\lambda_B = \frac{h}{mC_{th}}$

NOTE: $\lambda_B << \ell_L, \eta^{-\frac{1}{3}} \rightarrow$ quantum effects are negligible

$\omega_p (s^{-1})$ - plasma frequency = $\frac{C_{th}}{\lambda_D} = \left(\frac{4\pi n_e e^2}{M_E}\right)^{\frac{1}{2}} = 5.6 \times 10^4 \sqrt{n_e}$

$\tau = \frac{1}{\nu}$ = average time of one collision

$\delta = \frac{\text{electrostatic energy}}{\text{thermal energy}} \simeq \frac{e\phi}{kT}$

$\delta \rightarrow$ small implies plasma behaves thermodynamically as a perfect gas,
$p \simeq nkT$

α = degree of ionization

$\alpha < 10^{-4}$, $N_E << N_N$ weakly ionized

$\alpha > 10^{-4}$, $N_N << N_E$ strongly ionized

APPENDIX B

PLASMA MODELS

FIGURE 2

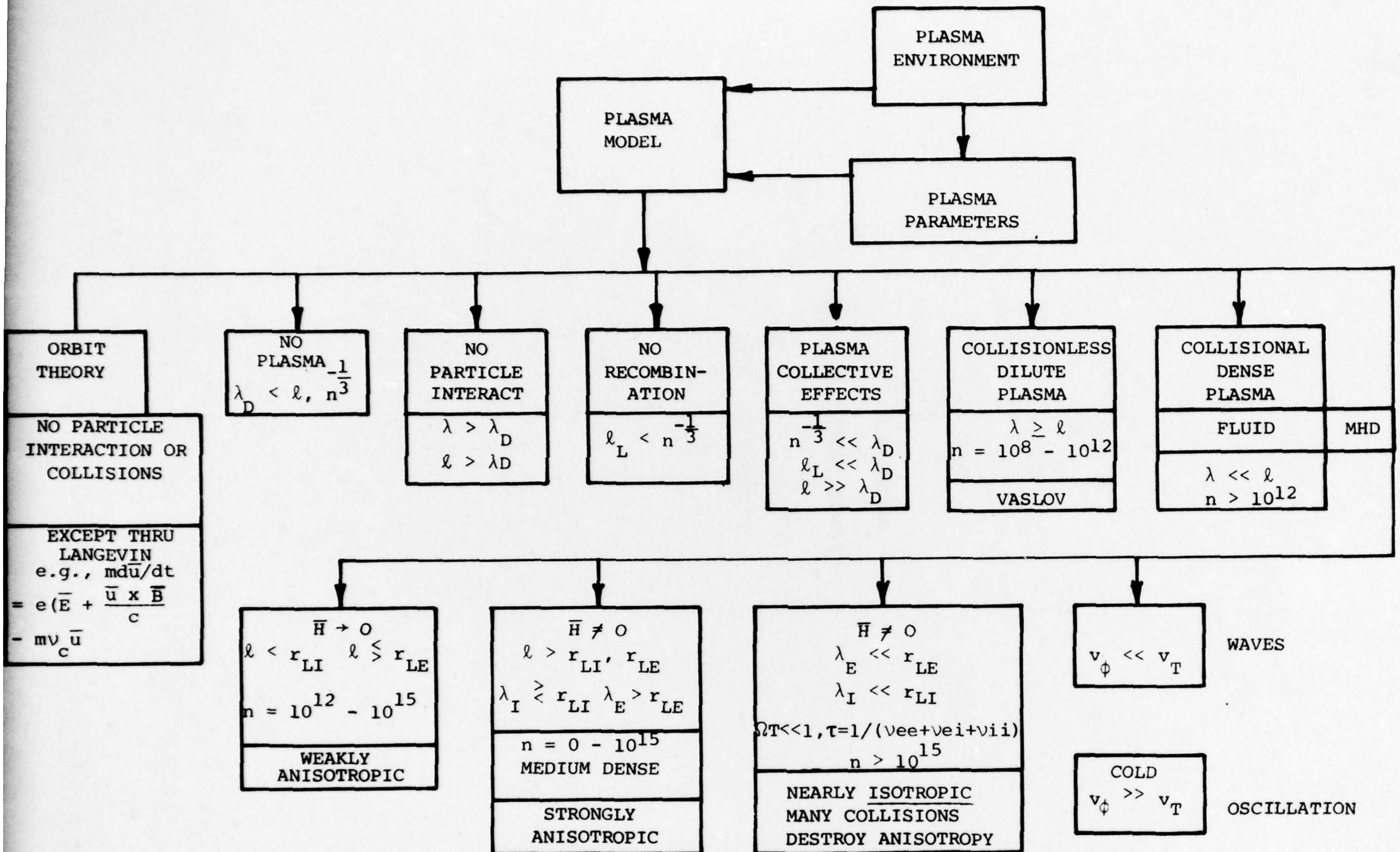

Figure 2 Plasma Models